

# *Environmental Quality of the Boula-Nuasahi Chromite Mine Area in India*

*Biswaranjan Dhal, Nigama Nanda Das,  
Banshi Dhar Pandey & Hrudaya Nath  
Thatoi*

**Mine Water and the Environment**  
Journal of the International Mine  
Water Association (IMWA)

ISSN 1025-9112

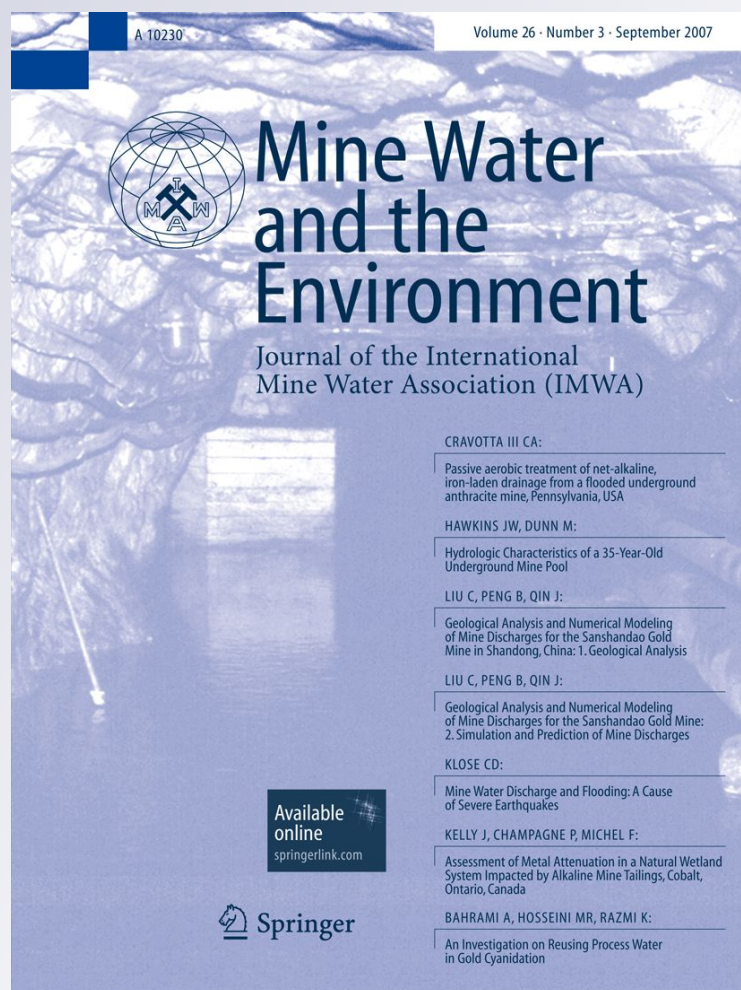
Volume 30

Number 3

Mine Water Environ (2011)

30:191-196

DOI 10.1007/s10230-010-0134-0



**Your article is protected by copyright and all rights are held exclusively by Springer-Verlag. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your work, please use the accepted author's version for posting to your own website or your institution's repository. You may further deposit the accepted author's version on a funder's repository at a funder's request, provided it is not made publicly available until 12 months after publication.**

# Environmental Quality of the Boula-Nuasahi Chromite Mine Area in India

Biswaranjan Dhal · Nigama Nanda Das ·  
 Banshi Dhar Pandey · Hrudaya Nath Thatoi

Received: 28 July 2010 / Accepted: 7 December 2010 / Published online: 24 December 2010  
 © Springer-Verlag 2010

**Abstract** Chromite mining can create hostile conditions for organisms in the surrounding environment. Overburden soil and mine water samples were collected and analyzed for their microbial diversity, nutrient content, and water quality at the Boula-Nuasahi Mine. Most of the water parameters that were measured exceed national/international standards. The microbial population was low (soil:  $45 \pm 0.06 \times 10^5$  bacteria,  $20 \pm 0.03 \times 10^5$  fungus) and the overburden soils have a low nutrient (N, P, K) content. The metal ions were found to have leached to nearby agriculture lands, making them less fertile for crop production. Overburden dumps and seepage water were found to be the main sources of chromium pollution.

**Keywords** Chromium · Mine water · Orissa · Overburden soil · Pollution · Toxicity

## Introduction

The mineral deposits of Orissa account for 95% of India's chromite, 92% of its nickel ore, 69% of its cobalt ore, 55% of its bauxite, 51% of its titaniferous magnetite, 40% of its limestone, 36% of its pyrophyllite, 33% of its iron ore (hematite), 26% of its sillimanite, 25% of its fireclay and garnet, 24% of its coal and zircon, and 20% of its vanadium ore resources (Ministry of Mines 2010). Chromite, the only economic ore of chromium, is considered to be one of Orissa's most important resources, with approximately 183 million tons of deposits located in the region's Sukinda and Baula-Nuasahi mining belts. Chromite is mostly found near Jajpur (16 mining leases; 4,320.93 ha mining area), and Keonjhar (5 mining leases; 2,013.123 ha mining area), the Dhenkanal districts (3 mining leases; 960.8 ha). The Bangur chromite mine lease of OMC Ltd. (Boula-Nuasahi) occupies an area of 145.85 ha (360.5 acres) in the Keonjhar district. Chrome and chrome concentrate is generally exported to China, Russia, Japan, and the Netherlands, totalling about 32.8 lakh (hundred thousand) tons of chromite ore in 2007–08 (Govt of Orissa 2009).

Chromite belongs to the spinel group and has the basic formula  $R^{++} R_2^{+++} O_4$ , where  $R^{++} = \text{Mg, Fe}$  with traces of Mn and Ni and  $R^{+++} = \text{Cr, Al}$  and Fe with traces of Ti and V. It has five major components, viz. MgO, FeO,  $\text{Cr}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ . Pure chromite contains 67.9% chromic oxide ( $\text{Cr}_2\text{O}_3$ ) by weight or 46.5% chromium by weight (Sahoo 1998).

Most of the chromite is extracted through open cast mining. In this study, we studied the environmental parameters of the Boula-Nuasahi chromite mine area, Orissa, India to assess the possibility of subsequent restoration and management of the mine site. Different parameters, such as nutrient content, water quality, and microbial

B. Dhal · B. D. Pandey (✉)  
 National Metallurgical Laboratory, CSIR,  
 Jamshedpur 831007, India  
 e-mail: bdpnml@gmail.com

N. N. Das  
 Department of Chemistry, North Orissa University,  
 Baripada 757003, Orissa, India

H. N. Thatoi  
 Department of Biotechnology, College of Engineering &  
 Technology, Bhubaneswar 751014, Orissa, India

### Present Address:

B. D. Pandey  
 Mineral Resources Research Division, Korea Institute  
 of Geoscience and Mineral Resources (KIGAM),  
 92, Gwahang-no, Yuseong-gu, Daejeon 305-350, Korea

diversity of the overburden dumps and mine drainage water were analyzed, and details are presented.

## Materials and Methods

### Study Area

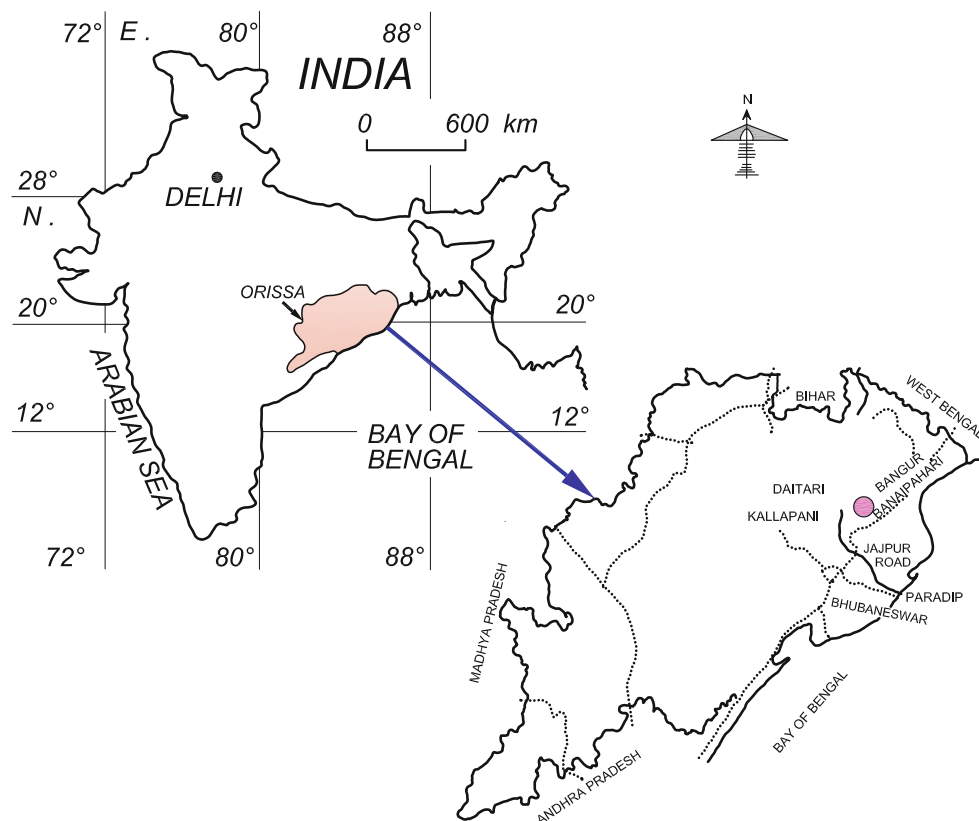
The Bangur mining lease of OMC (Orissa Mining Corp.) Ltd is located to the north of the village of Bangur in the Anandpur sub-division of Keonjhar District, Orissa. This area lies between longitude  $20^{\circ} 15'38''$ – $21^{\circ} 16'55''$  north latitude and  $86^{\circ} 19'14''$ – $86^{\circ} 20'10''$  east longitude (Fig. 1).

A tropical environmental and humid temperate climate prevails over this region. The area shows a sub-dendritic pattern with a low drainage density. River Salandi forms the principal drainage channel in the area, collecting the surface run off from its tributaries and seasonal streamlets. The area is rocky and before mining, there are small herbs and shrubs present. The shrubs are large (1–3 m or larger) and joined to each other with branching. At the time of open cast mining, the top soil and waste rocks were deposited in dumps. Groundwater seepage and mine water

are pumped by means of electrical pumps to the land surface, where it is used to irrigate approximately  $10 \text{ km}^2$  of agricultural land, and finally mixes with the irrigation canal of the Salandi River. This watercourse is used for agriculture, for bathing and washing by nearby residents, and is consumed by animals.

### Sample Collection

Altogether, six soil samples and three water samples were collected from different locations from the mining area. Soil samples collected from the mining site overburden dumps varied from fresh low grade ore to 15–16 year old dumps. Chromite overburden soil (COS-1) was collected from a 3 year old overburden dump, COS-2 (fresh low grade ore with soil), COS-3 (8–9 year old overburden dump), COS-4 (7 year old overburden dump), COS-5 (15–16 year old overburden dump), and COS-6 (agricultural land adjacent to a 15–16 year old overburden dump). The water samples that were collected from the mine site were designated as chromite mine water: CMW-1 from the underground seepage, CMW-2 (100 m deep quarry water), and CMW-3 (stored pond water). All the samples were collected and stored in sterile polythene bags and bottles at  $4^{\circ}\text{C}$ .



**Fig. 1** Filled circle Location of the Baula-Nuasahi (Bangur) chromite mine of Orissa



## Microbial Diversity in Overburden and Water Samples

Microorganisms were isolated using the dilution spread plate technique (Dhal and Thatoi 2007). In this process, 1 g of each soil was mixed with 100 mL of sterile distilled water, and then serially diluted using sterile water up to  $10^{-5}$  dilution. Each one mL of  $10^{-5}$  diluted sample was spread over three replicate nutrient and potato dextrose agar plates. Water samples (1 mL each) were also directly spread on the nutrient and potato dextrose plates, without any dilution. The plates were incubated for 48 h at 37°C in a BOD incubator. After the incubation period, different bacterial and fungal colonies grew on the nutrient and potato dextrose agar plates. The bacterial and fungal colonies were counted in the three replica plates and the average number was taken from the total number of microbes multiplied by the dilution factor for each sample.

## Physico-Chemical Analysis of Soil and Water Samples

The chemical compositions of the soil samples were analyzed using X-ray fluorescence spectrometry (XRF) (Philips, Germany). The nutrient contents of the soil samples were also analyzed using chemical methods. Physical parameters of the water samples, i.e. pH and conductivity (EC), were determined using a digital pH meter and a conductivity meter (Systonics PVT<sup>TM</sup>). Total alkalinity (TA) was measured using a phenolphthalein indicator, total dissolved solids (TDS) concentration was determined using the evaporation method, and dissolved oxygen (DO) was determined by titration against sodium thiosulphate, as described in APHA (1989). Total suspended solid (TSS) was determined by filtering a known volume of water sample using fibre filter paper. Biological oxygen demand (BOD) was evaluated at an interval of 5 days at 20°C whereas chemical oxygen demand (COD) was determined by titrating the sample against a standard ferrous ammonium sulphate solution. Total hardness (TH) and magnesium of the mine water samples were analyzed by titration using a standard EDTA solution, with Eriochrome Black T as an indicator. Calcium content was evaluated by titration with EDTA using murexide as an indicator. Chloride ( $\text{Cl}^-$ ) content was measured using potassium chromate as an indicator relative to silver nitrate. Sulphate ( $\text{SO}_4^{2-}$ ) and phosphate ( $\text{PO}_4^{3-}$ ) were determined using the turbidimetric method, comparing the results with the standard graphs and using barium chloride and stannous chloride as reagents, respectively. Total dissolved metals were determined by filtering the water samples using Whatman 42 filter paper, evaporating the aliquot to almost dryness, followed by digestion in concentrated HCl and analyzing the clear solution by atomic absorption spectrometer (AAS).

## Results and Discussion

### Soil Samples

The overburden soils were dry, rocky in nature, and low in nutrients (N, P, K and organic carbon). The colours of the soil were mainly light brown, black, light yellow, light black, and brown (Table 1). The texture ranged from clay, to city sand, and sandy. Soil pH was found to range from 6.2 to 8.4, with the pH of COS-4 being the lowest (6.2); all of the other samples had near-neutral to alkaline pH (6.8 to 8.4). The nutrient content as N (nitrogen) was found to range from 63 to 93 kg/ha. The nearby agricultural land soil has low N content (95 kg/ha). Phosphorous (P) was found to range from 2.4 to 3.6 kg/ha, and potassium (K) ranged from 67 to 205 kg/ha. The soils also contained a low percentage of organic carbon, ranging from 0.08 to 1.15%, reflecting the low microbial activity of the soil. Organic carbon content was also influenced by the age of the dumps.

Soil samples were analyzed for the composition of metal oxides by XRF, as summarized in Table 2. The principal metal, chromium, was in the form of chromium oxide ( $\text{Cr}_2\text{O}_3$ ) and was found to be highest in COS-3. Other metal oxides ( $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{NiO}$ ,  $\text{Fe}_2\text{O}_3$ , and  $\text{MnO}$ ) were present in all of the soil samples in minute to high amounts. COS-4 had a relatively high content of Si, Al, Fe, Ca, Mg, and Ni metal oxides. These metals could be leached using oxidizing agents for metal recovery. The alternative, allowing the metals to continue to leach out and contaminate nearby agricultural lands, as evident from the chemical analysis of COS-6, is clearly less desirable. The chemical analysis of COS-6 showed chromium (0.272 wt%  $\text{Cr}_2\text{O}_3$ ,  $\approx 1,860 \text{ mg Cr kg}^{-1}$  soil), along with Fe (3.85), Mg (1.95), Ca (0.88), Na (0.534), and K (1.48) wt% as major contaminants, and Ti (0.041), V (0.016), Mn (0.044), Cu (0.006), Ni (0.0133), and Zn (0.006) wt% as minor constituents.

Microbial diversity depends on the nutrient and moisture/water holding capacity of the soil to reproduce/degrade the constituents and increase the fertility of the soil. It has also been found that microbial populations decrease due to low nutrient contents and adverse environmental conditions (Table 3). The 13 year old overburden dump (COS-6) soil contained the highest microbial population ( $34 \pm 0.03 \times 10^5$  bacteria and  $15 \pm 0.04 \times 10^5$  fungal populations/g of soil) due to natural leaching of metals. The microbial population was lower in sample COS-4 ( $9 \pm 0.02 \times 10^5$  of bacteria and  $4 \pm 0.14 \times 10^5$  fungal populations/g of soil). As one would expect, the nearby agricultural land soil contained higher numbers of microorganisms ( $45 \pm 0.06 \times 10^5$  of bacteria and  $20 \pm 0.03 \times 10^5$  of fungal populations/g of soil). These populations are still very low compared to natural agricultural land soil (cells  $\times 10^{10-15}$ /g).

**Table 1** Nutrient content and characteristics of overburden samples

Characteristics of sample	Sample					
	COS-1	COS-2	COS-3	COS-4	COS-5	COS-6
Color	Light brown	Black	Light yellow	Light black	Brown	Light brown
Texture	Clay	City sand	City sand	Clay	City sand	Sandy
pH	7.4	8.1	6.8	6.2	7.8	8.4
N (kg/ha)	81	93	69	63	87	95
P (kg/ha)	3	3.6	2.4	2.8	2.6	3
K (kg/ha)	92	79	206	82	67	215
Organic carbon (%)	0.08%	1.15%	0.86%	1.15%	0.22%	0.51

COS Chromite Overburden soil, ha Hectare

**Table 2** Chemical composition of the soil samples

Chemical composition	Weight (%)					
	COS-1	COS-2	COS-3	COS-4	COS-5	COS-6
Al <sub>2</sub> O <sub>3</sub>	10.1565	12.3125	11.408	8.358	16.8144	17.6595
Na <sub>2</sub> O	0.4119	0.4576	0.5727	0.3202	0.1012	0.7204
MgO	13.4505	22.1625	20.4352	28.457	8.3258	2.6055
SiO <sub>2</sub>	50.9472	54.2144	34.4224	40.8945	53.3812	65.8902
K <sub>2</sub> O	0.2424	0.2048	0.3164	0.2268	0.2811	1.7949
CaO	2.6535	2.886	3.8192	2.7362	1.0848	1.2352
TiO <sub>2</sub>	0.4254	0.128	0.3452	0.3144	0.357	0.7324
V <sub>2</sub> O <sub>5</sub>	0.0525	0.0128	0.0813	0.0616	0.0334	0.0299
Cr <sub>2</sub> O <sub>3</sub>	2.3149	0.2639	19.3241	10.0495	1.0486	0.2721
MnO	0.1828	0.13	0.1458	0.098	0.1482	0.0569
Fe <sub>2</sub> O <sub>3</sub>	10.5408	5.7139	8.2435	7.8654	8.7462	5.5005
CaO	0.0109	0.006	0.0099	0.0095	0.0062	0.0044
NiO	0.0908	0.0384	0.0644	0.0983	0.069	0.0173
CuO	0.0089	0.0058	0.0073	0.0577	0.01175	0.0082
ZnO	0.0091	0.0046	0.0158	0.0149	0.0056	0.0069
Moisture content	8.6	1.5	0.8	0.5	9.6	3.5

**Table 3** Microbial diversity of different overburden soil samples

Average no. of colonies $\times 10^5/g$				
Sl. no.	Sample name	Bacteria	Fungus	<i>Actinomycetes</i>
1	COS-1	17 $\pm$ 0.04	11 $\pm$ 0.05	3 $\pm$ 0.12
2	COS-2	13 $\pm$ 0.14	5 $\pm$ 0.26	–
3	COS-3	20 $\pm$ 0.05	7 $\pm$ 0.07	–
4	COS-4	9 $\pm$ 0.02	4 $\pm$ 0.14	–
5	COS-5	34 $\pm$ 0.03	15 $\pm$ 0.04	6 $\pm$ 0.22
6	COS-6	45 $\pm$ 0.06	20 $\pm$ 0.03	8 $\pm$ 0.13

Results represent mean  $\pm$  standard error of triplicate sets

## Water Samples

Water samples were found to have a slightly lower pH (Table 4), in the range 5.94–6.32, than the Indian standards (pH: 6.5–8.5) for freshwater (river and streams). EC

(electrical conductivity) is a measure of the dissolved constituents in water, which affects taste and is important in deciding its potability (Pradeep 1998). The EC of three samples varied from moderate to high (750–1,110 ms/cm). However, the EC and pH of the water samples were within the permissible limits (EC: 2 ms/cm, pH: 5.5–9.0) of industrial waste water being used for land irrigation (WHO 1984). The TDS values (534–946 mg/L) crossed the WHO desirable limit (500 mg/L).

The concentration of total suspended solids (TSS), which plays an important role in waste water chemistry, ranged from 12 to 64 mg/L, whereas the permissible limit of TSS in inland surface water is only 100 mg/L. Differences in total alkalinity (132–210 mg/L) of the water samples represent the total carbonate and bicarbonate level, whereas the total hardness values (as CaCO<sub>3</sub>) in the three samples ranged from 258 to 305 mg/L, and were mostly within the prescribed limits (300 mg/L, IS: 2490 1981).

**Table 4** Water quality of chromite mine water samples

Sl. no.	Parameters	CMW-1	CMW-2	CMW-3	Standards
1	pH value	5.94	6.28	6.32	6.5–8.5 <sup>d</sup>
2	Temperature (°C)	26	29	28	30 <sup>d</sup>
3	Conductivity( $\mu$ Siemens/cm)	0.844	0.75	1.11	–
4	Total alkalinity, TA (mg/L)	210.0	165.0	132.0	300 <sup>d</sup>
5	Total solids, TS (mg/L)	1043.0	630.0	935.0	600 <sup>c</sup>
6	Total suspended solids, TSS (mg/L)	12	52	64	100 <sup>g</sup>
7	Total dissolved solids, TDS (mg/L)	946.0	534.0	848.0	500 <sup>c</sup>
8	Dissolved oxygen, DO (mg/L)	2.4	3.2	4.2	5.0 <sup>f</sup>
9	Biological oxygen demand, BOD (mg/L)	12.3	13.6	14.2	3.0 <sup>g</sup>
10	Chemical oxygen demand, COD (mg/L)	24.00	22.40	26.23	0 <sup>b</sup>
11	Total hardness, TH (mg/L)	305	292	258	300 <sup>d</sup>
12	Calcium (mg/L)	24	36	48	–
13	Magnesium (mg/L)	224.46	155.2	186.77	30 <sup>d</sup>
14	Chloride (mg/L)	369.2	255.6	210.1	1,000 <sup>a</sup>
15	Sulphate (mg/L)	175	210	230	1,000 <sup>d</sup>
16	Phosphate (mg/L)	0.42	0.73	0.64	–
17	Free CO <sub>2</sub> (mg/L)	36	27	29	–
18	Iron(mg/L)	1.63	0.96	1.09	–
19	Total chromium (mg/L)	0.9	1.25	0.76	2.0 <sup>g</sup>

<sup>a</sup> IS:2490 (1974), <sup>b</sup> IS:3307 (1974), <sup>c</sup> IS:3306 (1974), <sup>d</sup> IS:2490 (1981), <sup>e</sup> WHO (1984), <sup>f</sup> ISI-ICMR (1989), <sup>g</sup> MoEF (2000)

The hardness increases the boiling point of water and depends on anions such as carbonate, bicarbonate, sulphate, and chloride and major cations, such as calcium and magnesium (Trivedy and Goel 1984) which are all within the permissible limits.

Sulphate was also found to be within the permissible limit (1,000 mg/L, IS: 2490 1981) in all samples. Chloride content of the three water samples ranged from 210 to 370 mg/L and was also within the maximum permissible limits of India (1,000 mg/L, IS: 2490 1974). Phosphate, which is a critical nutrient for the growth of algae in water (Trivedy and Goel 1984) and can cause eutrophication, was very low.

In the three chromite mine water samples, the DO values ranged from 1.65 to 2.4 mg/L, and therefore did not meet the wastewater and bathing water criteria (5.0 mg/L or more, ISI-ICMR 1989). A low DO content can cause serious environmental problems. BOD was found to range from 12 to 14 mg/L, which exceeds the bathing water standards (3 mg/L or less, MoEF 2000), due to the nutrient and metal contamination in the water. COD ranged from 22 to 26 mg/L, which are high values for surface discharge water (IS: 3307 IS 1974).

The microbial diversity of the mine water samples was also studied using dilution plating and colony counting (Table 5). The colony forming units ranged from  $96 \pm 0.26$  to  $209 \pm 0.35$  colonies/mL of sample. Among the three samples, CMW-1 had the lowest number of colonies (96 and 51 colonies of bacteria and fungus, respectively). The

**Table 5** Microbial diversity of the water samples

Sl. no.	Sample name	Average nos. of colonies/1 mL		
		Bacteria	Fungus	Actinomycetes
1	CMW-1	$96 \pm 0.26$	$51 \pm 0.02$	–
2	CMW-2	$183 \pm 0.14$	$105 \pm 0.12$	–
3	CMW-3	$209 \pm 0.35$	$167 \pm 0.04$	–

Results represent mean  $\pm$  standard error of triplicate sets

CMW-3 water sample contained the highest number of microbial colonies (bacteria:  $209 \pm 0.35$ , fungus:  $167 \pm 0.04$ ). The relatively low microbial diversity of the water samples may be due to the metal ion contamination and unfavourable water parameters.

#### Other Aspects

Another important problem sometimes associated with mining is the formation of wastelands. Open cast mining and the creation of overburden dumps can do more than reduce forest yields; overburden dumps are often hostile to plant growth due to the existence of various stress conditions like low nutrient content, pH imbalance coupled with toxic and heavy metal ion accumulation, and poor water holding capacity (Misra et al. 1994).

Metals like iron, boron, copper, manganese, zinc are required in low concentrations for normal growth of plants, but an excessive amount is toxic to plants (Williamson

et al. 1982). In aqueous system, chromium exists primarily in two oxidation states: hexavalent chromium [Cr(VI)] and trivalent chromium [Cr(III)]. Changes in the oxidation state of chromium have a profound effect on toxicity and bio-availability. While Cr(VI) is toxic, Cr(III) is not only less toxic but is an essential nutrient (Mertz 1979). Mertz (1969) also reports that chromium is an important component of electron transport chains. Cr(VI) was found to be almost negligible in the water samples collected in this study, but the mining organizations in this area need to monitor this aspect carefully, considering that the adjoining water bodies are the only source of water for the local population.

## Conclusions

Mining can impact water and soil quality, depending on the chemical composition of the ores and waste dump materials, and factors such as slope, erosion potential, nearness to river, and natural drainage system also affect the extent of contamination. The magnitude of water pollution depends on the kind of treatment and mitigation measures adopted by the mining company. Of particular concern, in the case of chromite mining, is the chance for pollution by highly toxic hexavalent chromium. However, the Boula-Nuashahi chromite mines currently appear to have no sign of hexavalent chromium pollution. Several other water parameters are within permissible limits, while some exceed water quality standards. The overburden dumps contain various metals that may cause problem to the surrounding environments because of natural leaching of such metals over time. The adjacent agricultural land has been contaminated with such metals, which harms the productivity of the crops. The microbial diversity is also affected. So, the mining companies need to pay attention to the restoration and management of overburden dumps and mine drainage to reduce metal contamination of the adjoining area-soil and water bodies.

**Acknowledgments** The authors thank the Director, NML, CSIR, Jamshedpur, India, for permission to publish the paper. Thanks are also due to the Council of Scientific and Industrial Research (CSIR),

New Delhi, Govt. of India for the award of a Senior Research Fellowship to one of the authors (B. Dhal).

## References

- APHA (1989) Standard methods for examination of water and wastewater. APHA, AWWA, WPCF, 17th edit. Washington DC, USA
- Dhal B, Thatoi HN (2007) Isolation and characterization of bacterial strains occurring in Baula chromite mine soils of Orissa: potential for biotechnological applications. *Asian J Microbiol Biotechnol Environ Sci* 9:359–364
- Govt of Orissa (2009) Economic survey report. Mineral resources, Ch 10, pp 10/1–12. Accessible at: <http://www.epgorissa.org/M%20I%20Update/Mining%20Update,%20May,%202009.doc>
- Indian Standards (IS) (1989) Standards for disposal of wastewater. Indian Standards Institution and Indian Council of Medical Research (IS: 10500-1989), New Delhi, India
- IS (1974 and 1981) Standards for industrial discharge water. Indian Standards Institution and Indian Council of Medical Research : into inland surface waters: 2490, public sewers: 3306, and on land for irrigation: 3307, New Delhi, India
- Mertz W (1969) Chromium occurrence and function in biological systems. *Physiol Rev* 49:163–239
- Mertz W (1979) Chromium—an overview. In: Shapcott D, Hubert J (eds) *Developments in nutrition and metabolism*, Vol 2, chromium in nutrition and metabolism. Biomedical Press, Amsterdam, pp 1–14
- Ministry of Mines (2010) Annual report (2009–2010). New Delhi, India. Accessible at: <http://mines.nic.in/index.aspx?level=1&lid=346&lang=1>
- Misra AK, Pattnaik R, Thatoi HN, Padhi GS (1994) Study on growth and N<sub>2</sub> fixation ability of some leguminous plant species for reclamation of mine spoilt areas of Eastern Ghats of Orissa. Final Technical Report, MoEF, Govt of India, New Delhi, India
- MoEF (2000) Primary water quality criteria for bathing water. Serial # 93, 25th Sept 2000, Ministry of Environment and Forest, Govt of India, New Delhi, India
- Pradeep JK (1998) Hydrogeology and quality of ground water around Harapur, District Sagar (MP). *Pollut Res* 17(1):91–94
- Sahoo RK (1998) Chromium. In: Mohanty BK (ed) *Proc, geology and mineral resources of orissa, soc of geoscientists and allied technologists*, pp 155–178. Accessible at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.123.8606&rep=rep1&type=pdf>
- Trivedy RK, Goel PK (1984) Chemical and biological methods for water pollution studies. Environmental Publ, Karad, India
- WHO (1984) Guidelines for drinking water quality. World Health Org, Washington DC, pp 333–335
- Williamson NA, Johnson MS, Bradshaw AD (1982) Mine wastes reclamation. Mining Journal Books Ltd, London